IV.—*Results of Observations made at the Magnetical Observatory of Dublin, during the Years* 1840–43. *By the* Rev. HUMPHREY LLOYD, *D. D.*, PRESIDENT; *F. R. S.; Hon. F. R. S. E.; Corresponding Member of the Royal Society of Sciences at Gottingen; Honorary Member of the American Philosophical Society, of the Batavian Society of Sciences, and of the Society of Sciences of the Canton de Vaud, &c.*

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### FIRST SERIES.—MAGNETIC DECLINATION.

1. THE observations at stated hours, in the Magnetical Observatory of Dublin, commenced in November, 1838, and were at first taken twelve times during the day. Throughout the greater part of the following year, they were made at least eight times daily, with some variations as to the precise hours; and, at the beginning of the year 1840, the number of assistant observers was increased to three, and the observations were made *every alternate hour*, night and day, according to the comprehensive scheme recommended by the Council of the Royal Society, and followed at more than thirty observing stations in various parts of the globe. This plan has been in operation at the Dublin Magnetical Observatory until the end of the year 1843, when it was discontinued; four years' observations having been found sufficient for the determination of all the phenomena connected with the diurnal changes. The observations have been since continued upon a different and reduced scale, and with a view to other classes of phenomena.

I shall not, in this place, enter into any account of the instruments, or methods of observation, as these will be fully explained in the publication in which the observations themselves are presented in detail. I desire merely to

lay before the Academy the principal conclusions already arrived at. In the present paper, accordingly, I shall give the results of the observations of the magnetic declination during the four years referred to;* and in those which I hope hereafter to communicate, I shall discuss in like manner the observations of the other magnetic and meteorological elements made during the same period.

### *Diurnal Variation.*

2. A very limited series of observations is sufficient to exhibit the general features of the diurnal variation; but an extended one is necessary, if it be desired to ascertain with accuracy the mean amount of the changes. To determine these with precision, observations should be taken daily, at equal intervals not exceeding three hours, and be continued for one or more years. The course usually adopted in the reduction of such a series is, to combine separately the observations of each month, taking the arithmetical mean of all the results corresponding to the same hour. In this manner the course of the variation (which alters considerably throughout the year) is deduced for each month separately; and when the observations extend over several years, the monthly means of the separate years are to be again combined, each into a single mean.

Even this, however, is insufficient. The mean results thus obtained are deformed by the irregular fluctuations, which are often far greater than the regular changes; and it is necessary to omit the observations taken on days of disturbance, before we can deduce a correct mean from the results of any practicable series. This is proved in a striking manner by the observations of July, 1842. Owing to the great disturbance which took place on the 2nd and 4th of that month, the difference of the monthly means corresponding to 5 A.M., when these observations are retained and when they are omitted, amounts to $5'{\cdot}76$; so that the observations should be continued for fifty-seven years, in order to reduce the error to $0'{\cdot}1$.

In the final reduction of the Dublin observations, accordingly, all the results

* I have taken advantage of the delay which has occurred in the printing of this paper, to introduce the monthly mean results of the three following years, in the deduction of the annual and secular changes, and to make some other minor alterations of detail. The general conclusions originally arrived at are, however, not affected.

obtained on days of disturbance have been omitted,—those being defined to be days of disturbance, in which the sum of the differences between the separate results, and the monthly means corresponding to the same hours, exceeds a certain limit, which is about the double of its mean value. The number of separate observations actually combined, in deducing the monthly means for each hour, is, on the average, 86. The total number of observations employed exceeds 12,000.

3. The hours of observation, in accordance with the instructions of the Council of the Royal Society, were the even hours of Gottingen mean time. This being $1^h\ 4^m\ 50^s$ in advance of Dublin time, the observation hours are, nearly, the *odd hours of Dublin mean time.* The following are the differences of the monthly mean results corresponding to each hour, and the mean of the twelve, expressed in minutes. The *positive* numbers correspond to *easterly* deviations of the north pole of the magnet, and the *negative* to *westerly.*

Table I. Diurnal Variation of the Magnetic Declination.

| | 1 A.M. | 3 | 5 | 7 | 9 | 11 | 1 P.M. | 3 | 5 | 7 | 9 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January, . | +1′·09 | +0′·51 | +0′·69 | +0′·61 | +0′·69 | -2′·27 | -4′·27 | -2′·69 | -0′·81 | +0′·65 | +2′·67 | +3′·14 |
| February, | + 1·99 | + 1·15 | + 1·28 | + 1·46 | + 0·92 | - 2·46 | - 5·30 | - 3·44 | - 1·15 | + 0·59 | + 2·14 | + 2·80 |
| March, . . | + 2·08 | + 2·49 | + 2·37 | + 2·14 | + 1·85 | - 3·86 | - 7·21 | - 5·07 | - 1·17 | + 0·58 | + 2·94 | + 2·81 |
| April, . . . | + 2·36 | + 2·14 | + 3·15 | + 4·55 | + 2·52 | - 4·47 | - 8·75 | - 5·66 | - 1·51 | + 0·91 | + 1·94 | + 2·85 |
| May, . . . . | + 1·79 | + 2·54 | + 3·94 | + 5·16 | + 2·14 | - 4·12 | - 7·06 | - 5·13 | - 1·83 | + 0·29 | + 0·95 | + 1·31 |
| June, . . . . | + 2·09 | + 2·29 | + 4·18 | + 5·10 | + 2·55 | - 3·51 | - 7·16 | - 6·00 | - 2·42 | + 0·04 | + 1·02 | + 1·81 |
| July, . . . . | + 2·06 | + 2·54 | + 4·13 | + 4·31 | + 1·99 | - 3·56 | - 7·11 | - 5·64 | - 2·27 | + 0·09 | + 1·49 | + 1·98 |
| August, . | + 2·15 | + 2·52 | + 3·63 | + 3·70 | + 1·14 | - 4·68 | - 7·86 | - 4·98 | - 1·12 | + 1·05 | + 2·06 | + 2·37 |
| September, | + 1·77 | + 2·29 | + 1·52 | + 2·56 | + 0·85 | - 5·08 | - 7·58 | - 4·25 | - 0·32 | + 2·32 | + 3·02 | + 2·91 |
| October, . | + 2·06 | + 1·20 | + 1·37 | + 1·30 | + 0·99 | - 4·36 | - 6·16 | - 3·82 | - 0·28 | + 1·54 | + 3·56 | + 2·61 |
| November, | + 1·04 | + 1·08 | + 0·87 | + 0·58 | + 0·22 | - 3·02 | - 4·12 | - 2·30 | - 0·14 | + 1·02 | + 2·85 | + 1·91 |
| December, | + 0·59 | + 0·50 | + 0·44 | + 0·21 | + 0·21 | - 2·28 | - 3·45 | - 2·27 | - 0·45 | + 1·07 | + 3·03 | + 2·37 |
| Summer, . | + 2·04 | + 2·39 | + 3·43 | + 4·23 | + 1·87 | - 4·23 | - 7·59 | - 5·27 | - 1·58 | + 0·79 | + 1·75 | + 2·21 |
| Winter, . . | + 1·47 | + 1·15 | + 1·17 | + 1·05 | + 0·81 | - 3·05 | - 5·09 | - 3·27 | - 0·67 | + 0·91 | + 2.86 | + 2·60 |
| Year, . . . . | + 1.76 | + 1·77 | + 2·30 | + 2·64 | + 1·34 | - 3·64 | - 6·34 | - 4·27 | - 1·12 | + 0·85 | + 2·30 | + 2·40 |

4. The general features of the phenomenon, as deduced from these numbers, are the following:

i. Between 6 A.M. and 8 A.M. (the time varying with the season) the north pole of the magnet begins to move *westward*, and, therefore, the westerly decli-

nation *increases.* This movement continues until about 1 P. M., when the declination attains its *maximum.*

II. After 1 P. M. the north pole of the magnet moves *eastward*, and the declination *diminishes*, but at a slower rate than it had previously increased. This easterly movement continues until between 9 P. M. and 11 P. M., when the declination is a *minimum.*

III. There is a second, but much smaller, oscillation of the magnet during the night and morning; the north pole moving slowly to the *west* for a few hours before and after midnight, and afterwards returning to the *east* until between 6 A. M. and 8 A. M., when the declination is again a *minimum.*

IV. In summer the westerly movement during the night becomes nearly insensible. In winter, on the contrary, the easterly movement during the morning nearly vanishes; and the magnet is almost in a state of repose from 2 A. M. to 8 A. M.

V. In summer the morning easterly elongation is greater than the evening one; and, consequently, the greatest range is between 7 A. M. and 1 P. M. In winter, on the contrary, the evening easterly elongation is greater than the morning; and the greatest range is between 1 P. M. and 10 P. M. The total range is greater in summer than in winter.

These general characteristics of the diurnal variation may be most readily understood by a reference to Plates I. and II.

5. In order to determine the laws of the phenomenon with more precision, it will be desirable to express the difference between the declination at any hour, and the mean of the entire day, as a function of the time.

If $\Delta$ be taken to denote this difference corresponding to any time,

$$\Delta = \Sigma \ (A_i \cos ix + B_i \sin ix);$$

in which $x = n \times 15°$, $n$ being the number of hours, and parts of an hour, in the time reckoned from the epoch of the first observation, and $i$ any number of the natural series. Then, since observation gives the values of $\Delta$ corresponding to $n = 0, 2, 4, \&c. \ldots 22$, we have twelve equations of condition, from which twelve coefficients of the periodical function may be deduced by elimination. The first of these, $A_0, = 0$; the following are the values of the remaining eleven.

TABLE II. COEFFICIENTS OF THE EQUATION OF THE DIURNAL CURVE OF DECLINATION.

| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| January, . | + 2·426 | − 1·119 | + 0·313 | − 0·481 | − 0·059 | + 0·009 | − 0·260 | − 0·942 | − 0·362 | + 0·062 | − 0·121 |
| February, | + 2·941 | − 1·322 | + 0·607 | − 0·313 | + 0·097 | − 0·018 | + 0·264 | − 0·802 | − 0·257 | + 0·043 | − 0·085 |
| March, . . | + 3·988 | − 2·110 | + 0·777 | − 0·598 | − 0·119 | + 0·147 | + 0·688 | − 0·739 | − 0·112 | + 0·297 | − 0·019 |
| April, . . . | + 4·374 | − 2·912 | + 1.172 | − 0·235 | + 0·009 | − 0·051 | + 1·403 | − 0·681 | − 0·527 | + 0·133 | − 0·109 |
| May, . . . . | + 3·747 | − 2·670 | + 0·712 | + 0·047 | − 0·034 | − 0·010 | + 2·003 | − 0·109 | − 0·438 | + 0·173 | − 0·006 |
| June, . . . . | + 3·928 | − 2·597 | + 0·697 | + 0·018 | + 0·000 | + 0·044 | + 2·264 | − 0·551 | − 0·348 | − 0·029 | − 0·082 |
| July, . . . . | + 4·000 | − 2·410 | + 0·545 | − 0·163 | + 0·040 | + 0·047 | + 1·919 | − 0·453 | − 0·248 | + 0·014 | − 0·072 |
| August, . . | + 4·241 | − 2·617 | + 0·723 | − 0·238 | + 0·041 | + 0·002 | + 1·032 | − 0·121 | − 0·367 | + 0·078 | − 0·073 |
| September, | + 3·989 | − 2·548 | + 0·890 | − 0·233 | − 0·205 | − 0·124 | − 0·128 | − 0·355 | − 0·282 | + 0·416 | − 0·033 |
| October, . | + 3·452 | − 1·991 | + 0·667 | − 0·316 | − 0·009 | + 0·256 | − 0·335 | − 0·625 | − 0·285 | + 0·374 | − 0·069 |
| November, | + 2·363 | − 1·291 | + 0·253 | − 0·369 | − 0·036 | + 0·121 | − 0·436 | − 0·354 | − 0·185 | + 0·322 | + 0·031 |
| December, | + 2·053 | − 1·099 | + 0.055 | − 0·392 | − 0·088 | + 0·064 | − 0·578 | − 0·737 | − 0·170 | + 0·200 | − 0·021 |
| Summer, . | + 4·047 | − 2·626 | + 0·790 | − 0·136 | − 0·022 | − 0·017 | + 1·415 | − 0·379 | − 0·370 | + 0·131 | − 0·065 |
| Winter, . | + 2·871 | − 1·492 | + 0·445 | − 0·410 | − 0·036 | + 0·097 | − 0·109 | − 0·698 | − 0·228 | + 0·216 | − 0·049 |
| Year, . . | + 3·458 | − 2·058 | + 0·620 | − 0·272 | − 0·029 | + 0·041 | + 0·653 | − 0·537 | − 0·298 | + 0·173 | − 0·057 |

6. From the inspection of the numbers of this Table, we draw two important conclusions:

I. The values of the four latter coefficients, $B_4$, $A_5$, $B_5$, $A_6$, being small, all the terms of the series beyond the eighth may be neglected as inconsiderable. From this it follows, that *eight observations, made at equal intervals, are sufficient to determine the course of the diurnal variation.*

II. On comparison of the values of $A$ and $B$ for the separate months, it appears that there is a general resemblance in the course of the diurnal variation in the six months from April to September inclusive, as well as in the six months from October to March inclusive; and that thus the curves for the separate months distribute themselves naturally into two groups, in one of which the sun is to the north, and in the other to the south of the Equator.*

Hence, if we confine our attention to the three latter rows of the preceding Table, which give the values of the coefficients for the summer half-

* This fact appears likewise upon an examination of the immediate results of observation, as given in Table I.; and still more readily by the inspection of the curves in which these changes are graphically represented.—(See Plates I. and II.)

year, the winter half-year, and the whole year, respectively, the mean value of $\Delta$ at any hour will be expressed by the following equations, in which $x = n \times 15°$, $n$ denoting the number of hours, and parts of an hour, *reckoned from midnight:*

*Summer Half-year.*

$$\Delta_n = 4'{\cdot}288 \sin(x + 55° 44') + 2'{\cdot}653 \sin(2x + 231° 47')$$
$$+ 0'{\cdot}872 \sin(3x + 70° 6') + 0'{\cdot}189 \sin(4x + 253° 56').$$

*Winter Half-year.*

$$\Delta_n = 2'{\cdot}873 \sin(x + 77° 10') + 1'{\cdot}647 \sin(2x + 214° 56')$$
$$+ 0'{\cdot}500 \sin(3x + 72° 7') + 0'{\cdot}463 \sin(4x + 237° 47').$$

*Whole Year.*

$$\Delta_n = 3'{\cdot}519 \sin(x + 64° 18') + 2'{\cdot}127 \sin(2x + 225° 22')$$
$$+ 0'{\cdot}688 \sin(3x + 70° 40') + 0'{\cdot}322 \sin(4x + 242° 27').$$

7. It is manifest that the coefficients of the equation of the diurnal curve may be generally expressed as periodical functions of the time, reckoned from a given epoch of the year. For this purpose we have only to apply to the values of $A$ and $B$, belonging to the several months of the year (Table II.), the same process which has been already applied to the values of $\Delta$, corresponding to the several hours of the day. We thus obtain the following formulæ, in which $x = n \times 30°$, $n$ denoting the number of months, and parts of a month, reckoned from the 1st of January. The terms of the series which follow those here given are neglected as inconsiderable.

$$A_1 = + 3'{\cdot}458 + 0'{\cdot}927 \sin(x + 280° 37') + 0'{\cdot}541 \sin(2x + 294° 56');$$
$$B_1 = + 0'{\cdot}653 + 1'{\cdot}382 \sin(x + 297° 29') + 0'{\cdot}265 \sin(2x + 110° 21');$$
$$A_2 = - 2'{\cdot}058 + 0'{\cdot}830 \sin(x + 96° 39') + 0'{\cdot}339 \sin(2x + 83° 41');$$
$$B_2 = - 0'{\cdot}537 + 0'{\cdot}269 \sin(x + 239° 56') + 0'{\cdot}078 \sin(2x + 210° 48');$$
$$A_3 = + 0'{\cdot}620 + 0'{\cdot}264 \sin(x + 297° 5') + 0'{\cdot}280 \sin(2x + 281° 40');$$
$$B_3 = - 0'{\cdot}298 + 0'{\cdot}082 \sin(x + 119° 1') + 0'{\cdot}030 \sin(2x + 20° 26');$$
$$A_4 = - 0'{\cdot}272 + 0'{\cdot}194 \sin(x + 269° 36') + 0'{\cdot}100 \sin(2x + 147° 17');$$
$$B_4 = + 0'{\cdot}173 + 0'{\cdot}108 \sin(x + 144° 23') + 0'{\cdot}150 \sin(2x + 248° 50').$$

8. If we calculate the values of $\Delta$, corresponding to the *even* hours of Dublin mean time, by means of the formula of Art. 5 and the numbers of Table II., we obtain the following values, in which the *positive* numbers correspond to *easterly* deviations of the north pole of the magnet, as before.

TABLE III. DIURNAL VARIATION OF THE DECLINATION (CALCULATED VALUES).

| | 2 A.M. | 4 | 6 | 8 | 10 | Noon. | 2 P.M. | 4 | 6 | 8 | 10 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January, . | +0′·48 | +0′·73 | +0′·54 | +0′·88 | −0′·47 | −3′·77 | −3′·74 | −1′·65 | −0′·12 | +1′·64 | +3′·31 | +2′·19 |
| February, | + 1·42 | + 1·15 | + 1·39 | + 1·39 | − 0·40 | − 4·44 | − 4·76 | − 2·13 | − 0·29 | + 1·45 | + 2·62 | + 2·56 |
| March, . . . | + 2·22 | + 2·64 | + 2·01 | + 2·53 | − 0·59 | − 6·31 | − 6·70 | − 2·92 | − 0·21 | + 1·79 | + 3·27 | + 2·27 |
| April, . . . | + 2·06 | + 2·51 | + 3·98 | + 4·24 | − 0·64 | − 7·57 | − 7·80 | − 3·39 | − 0·08 | + 1·46 | + 2·48 | + 2·75 |
| May, . . . . | + 2·12 | + 3·12 | + 4·82 | + 4·35 | − 1·00 | − 6·29 | − 6·50 | − 3·44 | − 0·56 | + 0·73 | + 1·12 | + 1·53 |
| June, . . . . | + 2·02 | + 3·13 | + 4·95 | + 4·38 | − 0·35 | − 5·96 | − 7 10 | − 4·27 | − 0·91 | + 0·62 | + 1·41 | + 2·08 |
| July, . . . . | + 2·13 | + 3·36 | + 4·48 | + 3·55 | − 0·56 | − 5·95 | − 6·91 | − 3·94 | − 0·94 | + 0·91 | + 1·80 | + 2·05 |
| August, . . | + 2·17 | + 3·10 | + 3·89 | + 2·89 | − 1·58 | − 7·07 | − 6·93 | − 2·86 | + 0·15 | + 1·67 | + 2·30 | + 2·27 |
| September, | + 2·03 | + 1·95 | + 1·82 | + 2·49 | − 2·01 | − 7·19 | − 6·31 | − 2·19 | + 1·26 | + 2·75 | + 3·19 | + 2·19 |
| October, . | + 1·57 | + 1·27 | + 1·22 | + 1·64 | − 1·42 | − 6·04 | − 5·31 | − 1·89 | + 0·66 | + 2·76 | + 3·30 | + 2·28 |
| November, | + 1·04 | + 1·08 | + 0·60 | + 0·71 | − 1·25 | − 4·07 | − 3·44 | − 1·04 | + 0·36 | + 2·07 | + 2·69 | + 1·25 |
| December, | + 0·37 | + 0·61 | + 0·18 | + 0·46 | − 0·86 | − 3·24 | − 3·05 | − 1·31 | + 0·26 | + 2·16 | + 3·12 | + 1·34 |
| Summer, . | + 2·09 | + 2·87 | + 3·97 | + 3·67 | − 1·02 | − 6·69 | − 6·93 | − 3.35 | − 0·17 | + 1·35 | + 2·04 | + 2·15 |
| Winter, . . | + 1·19 | + 1·25 | + 0·98 | + 1·26 | − 0·83 | − 4·65 | − 4·49 | − 1·83 | + 0·12 | + 1·98 | + 3·05 | + 1·97 |
| Year, . . . . | + 1·64 | + 2·05 | + 2·49 | + 2·46 | − 0·93 | − 5·67 | − 5·72 | − 2·59 | − 0·01 | + 1·66 | + 2·55 | + 2·07 |

These numbers, together with those of Table I., are projected in curves in Plates I. and II. already referred to. Plate I. contains the curves of the six months of the summer half-year, together with the mean of the six ; Plate II. those of the six months of the winter half-year, and the mean. The scale is one-tenth of an inch to a minute of arc.

9. The hours of *greatest* and *least* declination are deduced from the general equation, by making $\frac{d\Delta}{dx} = 0$ ; they are consequently given by the formula

$$\Sigma i \left( B_i \cos ix - A_i \sin ix \right) = 0.$$

Substituting for $A_i$ and $B_i$ their numerical values (Table II.), and solving the resulting equations by approximation, we obtain the following results :

*Epoch of greatest Westerly Elongation.*

| | |
|---|---|
| Summer half-year, . . . . . . | $0^h$ $58^m$ P. M. |
| Winter half-year, . . . . . . | 0 47 |
| Whole year, . . . . . . . | 0 54 |

*Epochs of greatest Easterly Elongation.*

| | | |
|---|---|---|
| Summer half-year, . . | $6^h$ $50^m$ A. M. . | $11^h$ $8^m$ P. M. |
| Winter half-year, . . | 7 59 . . . | 9 38 |
| Whole year, . . . . | 7 12 . . . | 10 0 |

The hours of *mean* declination (or those at which the curve crosses the axis of abscissæ) are in like manner deduced from the equation

$$\Sigma(A_i \cos ix + B_i \sin ix) = 0.$$

The following are the results:

*Epochs of Mean Declination.*

| | | |
|---|---|---|
| Summer half-year, . . | $9^h$ $36^m$ A. M. . | $6^h$ $3^m$ P. M. |
| Winter half-year, . . | 9 30 . . . | 5 54 |
| Whole year, . . . . | 9 34 . . . | 5 59 |

10. The critical hours for the separate months are given in the following Table:

TABLE IV. HOURS OF GREATEST, LEAST, AND MEAN DECLINATION.

| Month. | Westerly Elongation. | Easterly Elongation. | | Mean Declination. | |
|---|---|---|---|---|---|
| | P. M. | A. M. | P. M. | A. M. | P. M. |
| January, . . | $0^h$ $52^m$ | $8^h$ $9^m$ | $10^h$ $21^m$ | $9^h$ $35^m$ | $6^h$ $5^m$ |
| February, . . | 1 1 | 7 25 | 10 51 | 9 41 | 6 13 |
| March, . . . . | 1 0 | 8 7 | 9 55 | 9 41 | 6 10 |
| April, . . . . | 0 55 | 7 11 | 11 12 | 9 45 | 6 3 |
| May, . . . . . | 0 58 | 6 55 | ——— | 9 31 | 6 30 |
| June, . . . . . | 1 21 | 6 40 | ——— | 9 47 | 6 45 |
| July, . . . . . | 1 11 | 6 9 | ——— | 9 43 | 6 43 |
| August, . . . | 0 52 | 6 11 | 10 55 | 9 20 | 5 47 |
| September, . | 0 35 | 7 31. | 9 25 | 9 13 | 5 1 |
| October, . . . | 0 30 | 8 7 | 9 3 | 9 25 | 5 9 |
| November, . | 0 25 | 7 55 | 9 23 | 9 7 | 5 12 |
| December, . | 0 30 | 8 9 | 9 35 | 9 11 | 5 31 |

The numbers of the preceding Table, notwithstanding some irregularities, exhibit very distinctly the influence of season upon the critical hours. The epoch of *greatest westerly elongation* occurs *latest* about the time of the summer solstice; and *earliest* in the last quarter of the year, or between the autumnal equinox and the winter solstice. The same thing holds with respect to the epochs of *mean declination*, which (as might have been expected) appear to be governed in great measure by the time of westerly elongation.

The epochs of *greatest easterly elongation* appear to be governed by the times of sunrise and sunset, and are, consequently, much more variable. The forenoon easterly elongation is *earliest* about the time of the summer solstice, and *latest* at that of the winter solstice; while the case of the afternoon easterly elongation is nearly the reverse. In the months of May, June, and July, in fact, there is no change in the direction of the movement during the night, but the needle is quiescent for a few hours after midnight, and then the north pole resumes its easterly movement until after 6 A. M.

The critical hours of greatest constancy throughout the year are those of the greatest westerly elongation, and those of the forenoon mean; the extreme difference between any of these hours, and the mean for the entire year, being twenty-eight minutes. The differences are much lessened, if *apparent* be substituted for *mean* time.

11. I proceed, in the next place, to state the results connected with the diurnal range.

The morning easterly elongation being greater than the evening one in summer, and less in winter, it follows that a complete view of the phenomena connected with the magnitude of the oscillation cannot be had, without taking into account the double range. This is accordingly done in the following Table, the first column of which gives the range of the *westerly* movement, between 7 A. M. and 1 P. M., nearly; and the second that of the succeeding *easterly* movement, from 1 P. M. to 10 P. M. nearly.

TABLE V. RANGES OF THE DECLINATION IN EACH MONTH.

| Summer Half-year. | | | Winter Half-year. | | |
|---|---|---|---|---|---|
| Month. | Westerly Movement. | Easterly Movement. | Month. | Westerly Movement. | Easterly Movement. |
| April, .... | 13′·3 | 11′·6 | October, ... | 7′·8 | 9′·7 |
| May, ..... | 12 ·2 | 8 ·4 | November, . | 4 ·8 | 7 ·0 |
| June, ..... | 12 ·3 | 9 ·2 | December, . | 3 ·9 | 6 ·6 |
| July, ..... | 11 ·6 | 9 ·2 | January, .. | 5 ·2 | 7 ·6 |
| August, ... | 11 ·8 | 10 ·2 | February, .. | 6 · | 8 ·1 |
| September, . | 10 ·1 | 10 ·8 | March, .... | 9 ·7 | 10 ·5 |
| Mean, ..... | 11 ·9 | 9 ·9 | Mean, ..... | 6 ·4 | 8 ·3 |

It appears from the foregoing Table, that (as above stated) the greatest range in summer is that of the westerly movement, its mean value being 11′·9; while, in winter, the greatest range is that of the easterly movement, and its mean value is 8′·3. It is remarkable, however, that the mean ranges of the easterly and westerly movements, for the entire year, are precisely equal, the mean value of each being 9′·1.

The *greatest* value of the maximum range is that of April, and its amount is 13′·3 ; the range then decreases until about the middle of July, and afterwards increases, attaining a second, but smaller maximum in August. The *least* value of the maximum range is that of December, and its amount is 6′·6, being one-half of the greatest value. The *mean* value of the maximum range, for the entire year, is 10′·1.

The unexpected fact, of the occurrence of the greatest ranges in April and August, was first noticed by BEAUFOY. He seemed to think, however, that the result was only an apparent one, and arose from the circumstance, that the times of observation approached more nearly the epoch of greatest elongation in April than in June. The fact has been since noted also by GAUSS, in his account of the Gottingen observations. " The differences" (of the declination at 8 A. M. and 1 P. M.), he observes, " are not greatest at the time of the summer solstice, but appear smaller in June and July than in April, May, and August ;" but he concludes, with BEAUFOY, that this was due to the accidental circumstance, that the *whole* range was not observed near the solstice, the time of

the greatest easterly elongation being then earlier than 8 A. M. It is manifest, however, that such an explanation will not apply to the result deduced, as in the present instance, from the diurnal curve ; and there can be no longer any doubt of the reality of the phenomenon.

12. The physical dependence of the changes of declination upon the sun is evident from the fact that they observe a *diurnal* and an *annual* period. The conclusion deducible from this fact has been confirmed by the leading features of the diurnal movement. Thus it has been long ago observed, that the time of greatest westerly elongation follows the sun's meridian passage at a nearly constant interval ; and that the times of greatest easterly elongation, in the morning and evening, are in like manner connected, although not so closely, with the hours of sunrise and sunset. The greater magnitude of the range, in summer than in winter, is another obvious confirmation of the same view.

We may, I believe, disregard, as wholly untenable, the hypothesis originally proposed by COULOMB, in which the influence of the sun is assumed to be *direct*, and the effect of magnetic polarity in that body. It is easy to show that, if such an action exist at all, it cannot certainly account for the principal part of the observed effect. But, without dwelling on the negative side of the question, I hope to show that the sun acts indirectly, by means of his heating power exerted upon the earth's surface. This has been assumed by CANTON, and since by Professor CHRISTIE, in the hypotheses which they have severally devised to account for the diurnal variation of the declination ; but the evidence upon which it rested did not extend beyond the facts which have just been stated. It will appear from the following examination, that the connexion between the changes of declination and those of temperature is more intimate than has been hitherto supposed.

13. The force which produces the deviation of the magnet from its mean position, at any moment of the day, is measured by the sine of the deviation,—or, since the deviation is small, by the angle of deviation itself, or by the ordinate of the diurnal curve ; and the sum of all these forces throughout the day, or the integral of the diurnal action, is measured by the area of the diurnal curve. If, then, the diurnal variation of the declination be the result of the diurnal variation of temperature, we should expect to find a marked correspondence between the areas of the diurnal curves of the two elements, throughout the year.

The following Table contains the computed values of these two functions, for the several months of the year, the units being one minute of declination, one degree of temperature, and one hour of time.

Table VI. Areas of the diurnal curves of Declination and Temperature.

| | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Declination, .... | 39·3 | 42·2 | 64·4 | 79·5 | 72·5 | 76·7 | 74·6 | 74·6 | 69·8 | 58·9 | 39·0 | 34·5 |
| Temperature, .. | 38.9 | 37·6 | 72·0 | 93·9 | 96·9 | 101.8 | 91·1 | 94·3 | 81·2 | 64·8 | 34·6 | 23·8 |

For the purpose of comparison, the preceding numbers are graphically projected in Plate III. figs. 1 and 2, one division of the scale corresponding to four minutes of declination, and to eight degrees of temperature. These curves exhibit in the clearest manner the correspondence between the two classes of phenomena, and leave no doubt whatever that they stand in the relation of effect and cause. The slight dissimilarities which exist between them are abundantly accounted for by the circumstance, that it is to the heating power of the sun, exerted upon the *earth's surface* (and not upon its atmosphere), that we must ascribe the changes of declination; and I venture to predict, that as soon as we are in possession of data respecting the diurnal changes of temperature of the earth's surface, sufficient for the purposes of a comparison such as that now made, the agreement of the laws will be found to be still more complete.

The same agreement appears, also, upon a comparison of the mean yearly values of the same functions, calculated for the four years; the following are the results.

Table VII. Areas of the diurnal curves of Declination and Temperature, for the separate years.

| | 1840. | 1841. | 1842. | 1843. |
|---|---|---|---|---|
| Declination, .... | 68·3 | 62·3 | 59·2 | 56·0 |
| Temperature, ... | 84·0 | 66·0 | 62·7 | 55·6 |

### *Annual and Secular Variations.*

14. The mean yearly values of the declination, for the seven years from 1840 to 1846, inclusive, are given in the following Table; the deviation of the north pole of the magnet from the astronomical meridian being measured from the north *eastward.* The third column of the Table contains the differences of the declination in the successive years, or the yearly amounts of the secular change.

TABLE VIII. MEAN YEARLY VALUES OF THE DECLINATION, FOR THE YEARS 1840–46.

| Year. | Declination. | Differences. |
|---|---|---|
| 1840 | 332° 30′·69 | |
| 1841 | 34 ·65 | + 3′·96 |
| 1842 | 43 ·55 | + 8 ·90 |
| 1843 | 50 ·10 | + 6 ·55 |
| 1844 | 53 ·43 | + 3 ·33 |
| 1845 | 59 ·75 | + 6 ·32 |
| 1846 | 333° 7 ·22 | + 7 ·47 |

If $n$ denote the number of years reckoned from any epoch, $D_0$ the declination at that epoch, and $\epsilon$ the change from year to year, the actual declination, $D_n$, will be given by the formula

$$D_n = D_0 + n\epsilon,$$

on the supposition that the change of declination is proportional to the time. But the middle of the year 1840 being taken as the epoch, the values of $D_n$, corresponding to $n = 0, 1, 2 \ldots 6$, are given in the preceding Table; so that we have seven equations for the determination of $D_0$ and $\epsilon$. Combining these equations by the method of least squares, we obtain

$$D_0 = 332^\circ\ 30'{\cdot}30\ ; \quad \epsilon = +\ 6'{\cdot}060.$$

Consequently the north end of the magnet moves to the *east* from year to year, and the westerly declination therefore diminishes, by 6′·06 annually, in its mean quantity. The amount (as will be seen from the Table) varies considerably in different years.

Subducting 3′·03 from the value of $D_0$ given above, the mean declination

for January 1, 1840, is 332° 27′·27. Wherefore, the mean declination at any time is

$$D_n = 332° \, 27'{\cdot}27 + 6'{\cdot}06 \times n,$$

$n$ denoting the number of years, and parts of a year, reckoned from Jan. 1, 1840.

15. Subducting the mean values for each year from those of the separate months, we obtain a series of numbers which represent the course of the *annual variation.* During the year 1840 the declinometer was twice readjusted; and from this, and other causes, the monthly values of the absolute declination for that year cannot be relied upon with certainty. The following Table contains the values of the differences for the three following years, together with their means for the whole period:

Table IX. Annual Variation of the Declination for the years 1841–43.

| Year. | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1841, ... | +0′·75 | +0′·92 | −0′·70 | −0′·12 | −2′·04 | −4′·11 | −2′·48 | −1′·80 | −0′·41 | +1′·24 | +3′·37 | +5′.40 |
| 1842, ... | −1.72 | −1·52 | −0·56 | −1·01 | −2·66 | −3·61 | −2·80 | −0·76 | +1·64 | +2·76 | +4·36 | +5·94 |
| 1843, ... | +0·29 | +0·51 | +0·85 | +0·32 | +0·05 | +0·13 | −1·71 | −2·76 | −1·93 | −0·18 | +1·50 | +2·99 |
| Means,... | −0·23 | −0·03 | −0·14 | −0·27 | −1·55 | −2·53 | −2·33 | −1·77 | −0·23 | +1·27 | +3·08 | +4·78 |

The following Table contains the corresponding numbers for the succeeding triennial period, with their means, and the means of all.

Table X. Annual Variation of the Declination for the years 1844–46, together with the mean of all.

| Year. | Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1844, .... | −0′·01 | +0′·24 | +1′·13 | +0′·08 | −1′·72 | −2′·56 | −1′·79 | −2′·18 | −0′·74 | +0′·46 | +3′·44 | +3′·66 |
| 1845, .... | −1·14 | +0·29 | +0·38 | +0·35 | −0·53 | −1·16 | −2·06 | −2·15 | −1·31 | +1·19 | +1·73 | +4·44 |
| 1846, .... | −1·34 | −0·73 | +0·32 | +1·99 | +1·06 | −1·09 | −3·14 | −1·84 | −0·96 | +0·78 | +2·17 | +2·76 |
| Means,. . . | −0·83 | −0·07 | +0·61 | +0·81 | −0·40 | −1·60 | −2·33 | −2·06 | −1·00 | +0·81 | +2·45 | +3·62 |
| Means of six years, | −0·53 | −0·05 | +0·24 | +0·27 | −0·98 | −2·06 | −2·33 | −1·92 | −0·62 | +1·04 | +2·76 | +4·20 |

The mean results for the two triennial periods, together with the means of all, are graphically represented in Plate III. figs. 3, 4, 5; the scale being 0·2 inch to one minute of arc. To facilitate comparisons hereafter instituted, the *positive* ordinates correspond to *westerly* deviations. The correspondence of the course of the variation during the two periods is as close as could be expected, the difference consisting chiefly in the epoch of the westerly maximum.

16. The following are the laws of the changes, as deduced from the mean results:

I. From the beginning of April to the beginning of July, the north end of the magnet moves to the *west;* the maximum of westerly declination takes place about the 8th of July, but the epoch varies considerably in different years.

II. During the remainder of the year (i. e. from the beginning of July to the beginning of April), the north end of the magnet moves to the *east;* the movement, however, is very slow during the first three months of the year.

III. The range of the westerly movement is 2·7 minutes; and that of the easterly 8·7 minutes. Thus, at the end of twelve months, the north end of the magnet has advanced to the east, by about 6·0 minutes, as has been already shown.

17. The annual variation of the declination was discovered by CASSINI in 1786.* It appeared from the observations of CASSINI, that the north pole of the magnet moved to the *east* from the vernal equinox to the summer solstice; and that, during the remaining nine months of the year, it moved to the *west.* The westerly movement, during the nine months, preponderated over the easterly, which took place during three; and thus the westerly declination was

* The determination of the annual variation is much more difficult than that of the diurnal, both on account of the much smaller frequency of the period, and the difficulty of preserving the instrument in the same unchanged condition during the much longer time, or of determining and allowing for its changes when they do occur. Accordingly, although the annual period may be traced in the observations of GILPIN, and is decidedly displayed in those of BOWDITCH, it has evaded the researches of recent observers. There is but a faint indication of its existence in the Gottingen observations, which were made at the hours of 8 A. M. and 1 P. M.; and Professor GAUSS and Dr. GOLDSCHMIDT find, in their analysis of these observations, no "important fluctuation dependent on season." A similar negative result is deduced by Dr. LAMONT from the Munich observations, which were made twelve times in the day.

greater at the close of the year than at the commencement. The difference was the yearly amount of the *secular* change.

The observations of CASSINI were made during five years, viz. from 1784 to 1788, inclusive. Although the annual variation at Paris was then greater than it is now at Dublin, the final means are less accordant; and M. KÆMTZ deduces from them the existence of a *double* oscillation. This conclusion, however, has arisen from what appears to be an erroneous mean value in the month of October, and is therefore not a legitimate interpretation of the results.

18. When we compare the course of the changes observed by CASSINI with those observed at Dublin, we find that the movements are precisely opposite. But, it is to be observed, the directions of the secular changes at the two periods are likewise opposed; and, putting together these facts, we are led to generalize the law as follows:

*From a little after the vernal equinox until a little after the summer solstice, the movement of the north pole of the magnet is* RETROGRADE, *or opposite in direction to the secular change; and during the remaining nine months of the year it is* DIRECT.

The remarkable relation between the annual and secular changes, here stated, may be observed on comparing the observations of BOWDITCH, in 1810, with those of CASSINI. At this time the westerly declination was *diminishing* at Salem, in Massachusetts, by about two minutes annually; and, in accordance with the preceding law, the direction of the annual movements is the *inverse* of that observed by CASSINI at Paris, in 1786, and agrees with that observed at Dublin at the present time. M. ARAGO, who notices these observations (*Annales de Chimie*, tom. xvi.), draws from them a different conclusion, and infers (although with an expression of doubt) that when the westerly declination diminishes from year to year, the period of CASSINI is transported from Spring to Autumn.

It further appears probable, that, at a given place, *the amount of the annual variation is related to that of the secular change, and vanishes when the latter vanishes.* This conclusion has been drawn by ARAGO, from the observations of GILPIN at London, in 1787–1793, and those of BEAUFOY in 1818–1820, as compared with those of CASSINI. At the former period, in fact, the secular change was only $+1'\cdot 0$ annually at London, and the annual variation was proportionally small; while, at the latter, both changes appeared to be evanescent.

19. The phenomena just described are, it is manifest, the resultants of two distinct changes,—namely, the *annual variation* properly so called, and the *secular change.* The amount of the latter is $+ 0'.5 \times n$, $n$ being the number of months elapsed. If this be subtracted from the numbers in the last row of Table X., reducing to the epoch July 1 (the middle of the year), we obtain the numbers of the following Table, which represent the course of the true annual variation. The *positive* numbers correspond to *easterly* deviations, as before.

TABLE XI. PERIODICAL PART OF THE MEAN ANNUAL VARIATION.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +2'·22 | +2'·20 | +1'·99 | +1'·52 | −0'·23 | −1'·81 | −2'·58 | −2'·67 | −1'·87 | −0'·71 | +0'·51 | +1'·45 |

The following is the equation of the curve of the annual variation, in which $x = n \times 30°$, $n$ being the number of months, and parts of a month, reckoned from January 1. We may probably neglect, as inconsiderable, all the terms after the second.

$$\Delta D = 2'543 \sin (x + 52° \, 57') + 0'.301 \sin (2x + 232° \, 33') \\ + 0'.108 \sin (3x + 117° \, 46') + 0'.112 \sin (4x + 26° \, 25') \\ + 0'.057 \sin (5x + 295° \, 7') + 0'.005 \sin 6x.$$

The curve itself is represented in Plate III. fig. 6, the scale being 0.2 inch to one minute of arc. For the sake of the comparison with the annual curve of temperature, presently to be referred to, the *signs* are all changed, and the *positive* ordinates correspond to *westerly* deviations.

It appears from the inspection of this curve, that the course of the annual variation (unlike that of the diurnal in this respect) is represented by a *single* oscillation. The *minimum* occurs in the beginning of February, and the *maximum* in the beginning of August; and the whole *range* of the change is 5·0 minutes. The curve crosses the axis of the abscissæ in the middle of May and in the beginning of November.

To obtain the mean value of the declination corresponding to any month in any year, the value of $\Delta D$, obtained above, must be added to that of $D$, given in Art. 14. The formula, therefore, is

$$D_n = 332^\circ\, 27'{\cdot}27 + 6'{\cdot}06 \times n + \Delta D;$$

$n$ denoting, as before, the number of years reckoned from January 1, 1840.

20. We have already seen that the diurnal changes of declination and temperature are related in a very remarkable manner ; and we should, therefore, naturally be led to expect a corresponding relation in the annual changes of the same elements. For the purpose of exhibiting it, I subjoin the differences between the mean temperatures of each month, and that of the entire year, as deduced from the observations made at the Magnetical Observatory during the years 1841–46.

TABLE XII. ANNUAL VARIATION OF TEMPERATURE.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| − 8°·38 | − 9°·04 | − 6°·24 | − 2°·03 | + 2°·95 | + 8°·93 | + 9°·18 | + 9°·46 | + 7°·22 | − 0°·90 | − 4°.16 | − 7°·02 |

The numbers of this Table are projected in Plate III. fig. 7, immediately below the corresponding curve of declination, the scale being ·05 of an inch to one degree of temperature. It will be seen, on a comparison of the two curves, that the annual variations of the declination and temperature present the most complete accordance, not only as to the hours of *maxima* and *minima*, but also in their entire course.* There is a slight, but systematic difference in the epochs of the *mean* values, those of the declination taking place about a *fortnight later* than those of the temperature. This is what we should be led *à priori* to expect, on the assumption that the magnetic changes are due to the

* Since this paper was written, I have learned that the correspondence between the annual changes of declination and temperature had been indicated by HORNER (*Gehler's Wörterbuch*) as a result of the Stockholm observations. The correspondence thus traced, however, does not extend beyond the fact, that the epochs of greatest and least declination coincide, nearly, with those of greatest and least temperature ; and, in fact, the results themselves, although the means of observations extending over the space of thirty years (1786–1815), are manifestly encumbered with too large an amount of observation error, to render any more detailed comparison possible. The same remark applies, yet more strongly, to the results of the Manheim observations, as quoted by KÆMTZ. In both of these cases, the most *easterly* position of the needle occurs at the time of *greatest temperature* of the year, and *vice versâ*.

changes of temperature of the earth's crust; for it is known that the epochs of mean temperature, as well as those of the maximum and minimum temperature of the *soil*, are *retarded*, and follow the corresponding epochs for the temperature of the *air* by an interval which is proportional to the depth.

These retardations, when observation shall have determined them with greater precision, will probably be found (in accordance with the results of Professor FORBES's experiments) to be different in different localities, depending upon the conductibility of the soil.

21. It remains to notice the bearing of the remarkable relations between the annual and the secular changes, stated in Art. 18. It would seem to follow from these relations, that the two classes of changes are physically connected; and therefore that the *secular*, as well as the *annual* variation, is due to the heating power of the sun exerted upon the earth's crust,—although not only the magnitude, but even the direction of the change is different at different times. It is not easy to frame even a conjecture as to the nature of such an agency, in the case of the secular change.

### *Disturbances.*

22. Having examined the *periodical* and the *secular* variations of the declination, it remains to consider those which, from our ignorance of their laws, we have been accustomed to call "*irregular*."

Professor KREIL seems to have been the first to notify the remarkable fact, that magnetic disturbances occur more frequently at certain hours than at others; and, that the *direction*, as well as the *frequency* of these movements, has a dependence upon the time of the day. Colonel SABINE has since made a more complete and elaborate examination of this question, in the discussion of the Toronto observations, and has arrived at conclusions for the most part confirmatory of those obtained by Professor KREIL.

In these investigations, however, those disturbances only are taken into account which exceed a certain arbitrary limit; and of these the *frequency* is considered without any reference to their *magnitude*. In examining the question of the periodicity of disturbances, I have thought it advisable to pursue a different course. I have taken the differences between each result, and the monthly mean corresponding to the same hour, and combined these diffe-

rences in the same manner as the errors of observation (to which they are analogous) are combined in the calculus of probabilities. The square root of the mean of the squares of these differences is, in fact, a quantity analogous to the *mean error*, and which we may therefore call the *mean disturbance*; and it is evident that its values, at the several hours of the day, and at the several seasons of the year, will serve to measure the probable disturbance to be expected at the corresponding times.

The values of this function have been deduced for the several hours of observation, in each month of the year 1843;* and those for the entire year are obtained from them by a repetition of the same process. They are given in the following Table:—

TABLE XIII. VALUES OF THE MEAN DISTURBANCE.

| | 1 A.M. | 3 | 5 | 7 | 9 | 11 | 1 P.M. | 3 | 5 | 7 | 9 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| January, . . | 1′·88 | 2′·25 | 1′·65 | 1′·27 | 1′·21 | 1′·47 | 1′·40 | 1′·63 | 1′·14 | 3′·07 | 0′·83 | 3′·94 |
| February, . | 2·00 | 2·20 | 1·63 | 1·09 | 0·98 | 1·43 | 1·83 | 2·89 | 2·49 | 2·72 | 7·64 | 2·42 |
| March, . . . . | 2·91 | 2·69 | 1·12 | 2·07 | 1·43 | 1·34 | 1·72 | 2·99 | 1·69 | 1·79 | 2·37 | 2·73 |
| April, . . . . | 2·75 | 3·43 | 2·44 | 1·18 | 1·65 | 2·11 | 2·53 | 2·06 | 4·02 | 3·29 | 3·34 | 3·83 |
| May, . . . . . | 2·90 | 3·01 | 1·97 | 1·61 | 1·61 | 1·56 | 1·72 | 1·93 | 1·87 | 0·92 | 2·85 | 10·96 |
| June, . . . . . | 2·58 | 2·24 | 1·99 | 1·78 | 2·63 | 2·01 | 3·14 | 2·08 | 1·67 | 1·14 | 1·28 | 1·95 |
| July, . . . . . | 3·67 | 3·33 | 2·56 | 2·61 | 3·25 | 2·99 | 3·30 | 1·63 | 1·78 | 1·36 | 4·89 | 3·47 |
| August, . . . | 4·41 | 1·96 | 4·02 | 1·48 | 1·52 | 2·00 | 2·08 | 2·25 | 2·20 | 1·31 | 2·14 | 1·42 |
| September, . | 3·08 | 2·09 | 2·65 | 3·73 | 2·70 | 2·39 | 2·16 | 1·79 | 2·23 | 2·54 | 3·79 | 2·63 |
| October, . . . | 2·76 | 3·39 | 1·16 | 2·46 | 1·96 | 1·76 | 2·04 | 1·89 | 1·33 | 3·95 | 3·22 | 2·58 |
| November, . | 2·14 | 1·21 | 1·79 | 1·09 | 1·17 | 1·75 | 1·68 | 2·17 | 1·52 | 1·70 | 1·12 | 1·64 |
| December, . | 1·18 | 1·03 | 1·16 | 0·80 | 0·99 | 1·74 | 1·56 | 1·41 | 1·93 | 3·16 | 2·01 | 1·67 |
| Means, . . . . | 2·81 | 2·52 | 2·16 | 1·93 | 1·89 | 1·93 | 2·17 | 2·11 | 2·12 | 2·44 | 3·47 | 4·07 |

These numbers show that the mean disturbance follows a law of remarkable regularity in dependence upon the hour. During the day,—i. e. from 6 A.M. to 6 P.M.,—it is nearly constant. At 6 P.M. it begins to increase, and arrives at a maximum a little after 10 P.M.; and it then decreases with the same regularity, and arrives at its constant day-value about 6 A.M.

* I have chosen this year, because in it the irregular changes were comparatively small; and, the number which expresses their frequency, in consequence, bearing a larger proportion to that which denotes their magnitude, any regular law to which they are subject will be more readily apparent.

23. The preceding results are independent of the *direction* of the disturbance. If, however, we take the sum of the squares of the easterly and westerly deviations separately, we find that the *easterly* disturbances preponderate during the night, and the *westerly* during the day; the former are, however, much more considerable than the latter, and the difference reaches a maximum about 10 P.M.

Let $\Sigma\Delta_+^2$ denote the sum of the squares of the positive, or easterly disturbances, and $\Sigma\Delta_-^2$ that of the negative, or westerly; then the mean values of the function $\sqrt{\left(\frac{\Sigma\Delta_+^2-\Sigma\Delta_-^2}{n}\right)}$ are the following. The values in which the *easterly* disturbances preponderate are distinguished by the *positive sign*, and *vice versâ*.

TABLE XIV. MEAN VALUES OF $\sqrt{\left(\frac{\Sigma\Delta_+^2-\Sigma\Delta_-^2}{n}\right)}$.

| 1 A.M. | 3 | 5 | 7 | 9 | 11 | 1 P.M. | 3 | 5 | 7 | 9 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| +1′·43 | +1′·05 | −1′·18 | −1′·15 | −1′·07 | −0′·83 | −0′·80 | −1′·12 | −0′·54 | +1′·67 | +2′·82 | +3′·37 |

It thus appears that the mean disturbance observes a regular daily period, both in *magnitude* and *direction;* and this period, it is worthy of remark, is precisely the reverse of that of the regular diurnal movement,—the mean *position* of the magnet being nearly constant during the *night*, the mean *disturbance* during the *day*;—the principal oscillation of the magnet, in the *regular* movement, being to the *west* during the *day*, while that of the *irregular* movement is to the *east* during the *night*.

24. From these remarkable relations it seems evident that the two classes of phenomena are physically connected; and I am inclined to regard the disturbance which prevails about 10 P.M., as an *irregular reaction* from the regular day movement, and dependent upon it both for its periodical character and for its amount.

If this hypothesis be a just one, it will, of course, follow that the magnitude of the mean disturbance will vary in some direct proportion to the daily range, and should, therefore, be greater in summer than in winter. This appears to

be established by the following Table, which contains the values of $\sqrt{\left(\frac{\Sigma\Delta^2}{n}\right)}$, corresponding to the several months of the year:

TABLE XV. ANNUAL VARIATION OF THE MEAN DISTURBANCE.

| Jan. | Feb. | March. | April. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2′·01 | 2′·96 | 2′·16 | 2′·85 | 3′·73 | 2′·11 | 3′·06 | 2′·42 | 2′·72 | 2′·51 | 1′·63 | 1′·67 |

These numbers are somewhat irregular; but if they be combined in periods of three months, taking the square root of the mean of the squares, we obtain the following numbers, in which the existence of an *annual period* is evident:

| | |
|---|---|
| February, March, April, . . . . | 2′·68 |
| May, June, July, . . . . . . . . | 3′·04 |
| August, September, October, . . . | 2′·55 |
| November, December, January, . . | 1′·77 |

The mean disturbance, for the entire year, is 2′·56.

25. It by no means necessarily follows, from the results now stated, that *all* disturbances have a periodical character. There probably are *two classes* of disturbances, the results of distinct physical causes, of which one observes a period, while the other is wholly irregular; and it is manifest that, in such a case, the period of the former will necessarily be impressed upon the *resultant* mean disturbance. We have, I think, also grounds for concluding that these two kinds of disturbances are further distinguished by the important characteristics,—that those of the former class are *local* (depending, as they do, upon the time at the place of observation), while those of the latter are *universal*, and belong to the phenomena which have hitherto so much engaged the attention of observers.

Of the periodical disturbances the principal (if not the only one) is that which occurs about 10 P.M., and which causes the north pole of the magnet to deviate to the east. The epoch of the maximum of easterly deflection varies, however, between very wide limits, being sometimes before 8 P.M., and sometimes later than 1 A.M.; and hence it is evident, that its effect on the monthly

mean curve is to produce a *general increase* of the ordinate between these limits of time, as well as the *maximum* at 10 P.M.

We learn from the consideration of these facts, that the ordinary mode of grouping the observations, by taking the mean of all the results at the same hour,—although it truly gives the *mean* diurnal curve for the period embraced by the observations,—does not represent the average actual course of the movement during one day. In order to obtain the *representative*, or *type* curve (as it may be called), it seems necessary to treat the ordinates and abscissæ as independent variables, and to take,—not the means of the ordinates corresponding to certain definite abscissæ,—but the means, both of the abscissæ and ordinates, *corresponding to the time of the phenomenon.* The former of these will give the *mean epoch* of the disturbance, and the latter its *mean amount.*

We find, in this manner, that the mean epoch of the periodical disturbance is a few minutes before 10 P.M. Its mean magnitude is 10′·0; and its mean duration is an hour and a half.